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NORSK GRANSKINGSRAPPORT Patentsøknad nr.
NORWEGIAN SEARCH REPORT Patent application no. 19983911

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1999.09.07

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"Alginatkapsler til bruk ved behandling av hjernesvulst"

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This invention is in the field of the treatment of tumours which are localized within the central nervous system (CNS) and of primary and secondary (metastatic) cerebral-spinal malignancies, and it provides new compositions and delivery systems useful in such therapy.

Primary brain tumours (gliomas) have several unique biological features compared to other metastatic tumours. They are confined within the central nervous system and metastatic spread to other organs is virtually non-existent. Even though these tumours show a high degree of invasion into the brain they have a tendency to recur after treatment in positions where they originally were found. The tumours are highly heterogeneous and consist of numerous cell types with different phenotypic properties.

At present the treatment of choice is surgery followed by radiotherapy and chemotherapy. Patients with the most malignant forms of brain tumours (glioblastomas) have a severe prognosis with a survival of approximately 10 months after diagnosis. There is therefore an urgent need for new treatment strategies for this particular group of tumours. Since the tumours have a tendency to recur at its primary site, new local treatment strategies are needed. Furthermore since these tumours consist of numerous tumour cells with different phenotypic properties, the treatment of choice should be capable of targeting different tumour cell types.

During recent years much attention has been focused on gene therapy, where reversion of the malignant phenotype by downregulation of oncogene expression or insertion of normal tumour-suppressor genes have been

tried. Immune stimulatory factors such as cytokines that are designed to enhance the recognition and rejection of tumours by the immune system have also been introduced. Furthermore, cells have been modified to allow direct delivery of gene products to tumour cells, increasing their susceptibility to pharmacological agents. Papers which describe these developments include (i) Curr Opin Oncol, 7, (1995), pages 94-100; (ii) Curr Opin Biotechnol, 5, (1994), pages 611-616; (iii) Cancer Res, 53, (1993), pages 2330-7; (iv) Hum Gene Ther, 4, (1993), pages 451-60; (v) Hum Gene Ther, 5, (1994), pages 153-164; and (vi) Trends Pharmacol. Sci, 14, (1993), pages 202-208.

Despite this extensive research during recent years, there are major obstacles which impede the transition between experimental research and clinical treatment of malignant brain tumours. One problem is to prevent immuno-rejection of genetically modified cells after intracranial implantation. In addition, it is difficult to achieve an efficient gene transfer, as well as a prolonged gene expression within the appropriate cells.

Other tumours which are localized within the central nervous system and which are often difficult to treat successfully include tumours derived from astroglial and oligodendroglial cells, for instance:

Astrocytomas

- Low grade astrocytomas (astrocytomas grade 1 and 2)
- Anaplastic astrocytoma (astrocytoma grade 3)
- Glioblastoma multiforme (astrocytoma grade 4)
    - including secondary glioblastoma,

i.e. tumours that have differentiated from astrocytomas with lower grade
- primary glioblastoma, i.e. tumours that occur as primary glioblastomas *de novo*
- giant cell glioblastoma
- gliosarcomas
- gliomatosis cerebri

Oligodendrogliomas
- including oligodendroglioma (WHO grade II)
- anaplastic oligodendroglioma (WHO grade III)

Mixed Gliomas
- Oligoastrocytoma (WHO grade II)
- Anaplastic oligoastrocytoma (WHO grade III)

Ependymal tumours
- Ependymoma (WHO grade II)
- Anaplastic ependymoma (WHO grade III)
- Subependymoma (WHO grade I)

Embryonal tumours
- Central neuroblastoma
- Ependymoblastoma
- Medulloblastomas
- Supratentorial PNETs

Neuroblastomas
- Olfactory neuroblastoma
- Neuroblastic tumours of the adrenal gland and sympathetic nervous system

For most of these tumours, the first treatment of choice is surgery followed with radiotherapy and/or with chemotherapy. However, complete tumour removal is often difficult by surgical procedures, whilst follow-up

radiotherapy and chemotherapy are also sometimes not completely successful due to radioresistance and/or difficulties in delivering therapeutic doses of cytotoxic drugs.

We have now found, in accordance with the present invention, that such problems as these can be overcome by encapsulating producer cells which are capable of expressing a molecule which is an inhibitor of CNS tumour growth in immuno-isolating devices such as alginate microbeads.

Thus, in its broad aspect, the present invention provides an encapsulated producer cell capable of expressing a molecule which is an inhibitor of CNS tumour growth.

The present invention also provides a method for the treatment of CNS tumour, which comprises implanting at the site of the tumour an encapsulated producer cell which is capable of expressing a molecule which is an inhibitor of the growth of said tumour.

Further, the present invention provides a method for the preparation a pharmacological product for the treatment of a CNS tumour, which comprises encapsulating within an immuno-isolating matrix a producer cell capable of expressing a molecule which is an inhibitor of the growth of said tumour.

In one embodiment of the invention the producer cells contemplated for use herein include genetically engineered cells that produce molecules e.g. proteins, peptides and polysaccharides, that will either directly interact with tumour cells or indirectly with tumour or host cell communication pathways. Other useful producer

cells contemplated herein are specialized cells which produce monoclonal antibodies as for instance hybridoma cells, or even naturally occurring cells which are capable of expressing tumour inhibiting molecules.

It is well known that tumour growth is dependent on specific cellular interactions with the host, mediated via specific growth factors that regulate tumour cell growth in rather complex ways. The tumours depend in this respect on nutrients mediated via newly formed blood vessels supplied by the host. Several tumour/host cellular interaction pathways have during the last years been identified and described in the literature.

Accordingly, one class of producer cell useful herein are those which can express proteins or peptides that will interact with tumour/host communication pathways. For instance, useful producer cells include those which produce proteins and peptides which affect tumour neovascularization as for instance thrombospondin, endostatin, angiostatin and prolactin, proteins which interfere with the tumour cells' relationship to the extracellular matrix, for instance protease inhibitors such as tissue inhibitors of metalloproteinases, and proteins and peptides which affect the immune system, including all the various classes of interleukins.

Another preferred class of producer cell is constituted by those which express proteins or peptides which interact directly with the tumour cells themselves. For instance, useful producer cells of this category include: hybridoma cell lines that produce monoclonal antibodies which interact directly with a receptor of the tumour, for example cell growth factor receptors which affect the tumour cells such as epidermal growth factor

receptor (EGFr), platelet derived growth factor receptors AA and BB, acidic and basic fibroblast growth factor receptors, transforming growth factor receptor alpha and beta, the different classes of vascular endothelial growth factor receptors (VEGFR-1 and VEGFR-2), tyrosine kinase receptors with immunoglobulin and EGF-like domains as, for instance, TIE-1 and TIE-2/tek, heptaocyte growth factor (scatter factor); or monoclonal antibodies directed against various classes of integrin receptors; monoclonal antibodies directed against CD-44; monoclonal antibodies directed against CDK/cyclin complexes; monoclonal antibodies directed against FAS; monoclonal antibodies directed against glycolipids on the cell surface; monoclonal antibodies directed against glycoproteins; and monoclonal antibodies directed against proteins derived from the expression of specific oncogenes.

Of particular interest in some circumstances are producer cells whose production of tumour growth-inhibiting substances can be switched on and off by pharmacological means, for instance producer cells with pharmacologically-inducible gene expression as, for example, tetracycline-activated gene expression.

Any cell line which is transfectable may be used in accordance with this invention. The cell lines should be permanent, i.e. able to undergo unlimited cell division, and preferably are non-human and non-tumorigenic.

Examples of such cell lines which are freely commercially available from the American Type Culture Collection, 10350 Linden Lake Plaza, Manassas, Virginia 20109, USA, are:

Cell Line	ATCC number	Description
H528	HB 8509	mouse B cell myeloma
293	CRL 1573	human transformed primary embryonal kidney
NIH/3T3	CRL 1658	NIH swiss mouse, embryo
COS-7	CRL 1651	African green monkey, kidney, SV40 transform
BHK-21	CCL 10	Hamster kidney, normal
CV-1	CCL 70	African green monkey, kidney, normal
CHP-234	CRL-2272	Neuroblastoma, brain, human
Rat2	CRL-1764	Embryo, thymidine kinase mutant, rat
Namalwa	CL-1432	Burkitt's lymphoma, human

In accordance with the present invention, the producer cells are encapsulated in immuno-isolating matrices which are capable of providing a stable, *in situ* delivery system of expressed protein or other molecule which can interfere with tumour growth and progression without immuno-rejection of the producer cells.

Biocompatible polymers are suitably used as the encapsulating matrices. A preferred immuno-isolating encapsulating matrix is provided by alginate beads.

The encapsulation of cells within alginate beads is a well known technique for immobilising cells and other substances, and has previously been used in the treatment of diabetes mellitus, in the production of monoclonal antibodies, and in other medical areas, as has been described in the literature. However, as far as we

are aware, this drug delivery technique has never before been proposed for the delivery of CNS tumour inhibiting substances in situ at the site of the tumour.

Generally, the use of alginate as an immobilisation matrix for cells involves mixing a suspension of the cells with an Na^+ alginate solution, whereafter the mixture is dripped into a solution containing multivalent cations (usually Ca^{2+}). The droplets form gel spheres instantaneously entrapping the cells in a three-dimensional lattice of ionically crosslinked alginate. This immobilisation procedure can be carried out under very mild conditions and is therefore compatible with most living cells. For a detailed description both of the theory and practice of the technique, the reader is directed to the paper "Alginate as Immobilization Matrix for Cells" by Smidsrød and Skjak-Braek in Trends in Biotechnology, March 1990, Vol. 8, No. 3, pages 71-78.

A currently preferred method for forming producer cell-encapsulated calcium alginate beads in accordance with this invention is as follows. Sodium alginate is dissolved at a concentration of from 1-2% in water or isotonic saline. The alginate solution is membrane sterilized, and the producer cells are then added and isotonicity adjusted. Calcium alginate beads are formed by dripping the sodium alginate-producer cell solution into a bath of calcium chloride (0.05-0.25 M), either manually but preferably using an electrostatic bead generator which establishes an electrostatic potential of 5 to 7 kV between the alginate feed needle and the gelling bath. By adjusting the needle diameter (e.g. from 0.1 mm to 0.4 mm), the flow rate (e.g. from 5 ml/hr to 30 ml/hr) and the voltage applied, beads of comparatively uniform diameter of from 100-400 μm can be

generated. The homogeneity of the beads is controlled by adjusting the salt concentration in the gelling bath, from 0 to 200 mM NaCl, with the higher salt concentration giving greater homogeneity. The beads are allowed to harden in the gelling bath, and then may be transferred to a coating solution for the purpose of adjusting pore size and increasing bead strength. Suitable coating agents are poly-L-lysine and chitosan, the latter having the advantage of imparting a bioadhesive cationic charge to the beads. If desired, an additional layer of alginate can be applied following the coating procedure, in order to reduce the bioadhesiveness of the initial coating without deleteriously affecting its strength and pore regulating effects.

Although encapsulation of the producer cells within alginate beads is preferred, it is within the scope of this invention to employ other suitable encapsulation techniques. For example, the encapsulation of the producer cells may be effected using solutions of chitosan which may be gelled by using natural biopolymers such as scleroglucan or alginate or crosslinked by the use of appropriate crosslinking agents such as dialdehydes. In another method, the producer cells may be encapsulated in agar or agarose by suspending the cells in pre-warmed solutions of agar or agarose and gelling by rapid cooling such as by gelling droplets of agar or agarose in a cold isotonic bath. Yet another method of encapsulation is by use of biocompatible polymeric substances such as polylactic acid copolymers and polyethylene glycol acrylate derivatives. Still further techniques for encapsulating producer cells will suggest themselves to those skilled in the encapsulation art.

It is contemplated that the encapsulated producer cells of this invention will be placed into the tumour cavity following conventional bulk tumour removal by surgery. Shortly after surgery the tumour burden is minimal and many patients have a symptom-free period before recurrence occurs. Since surgery is a traumatic event, the remaining tumour cells will try to establish new biochemical interaction pathways with the host. This involves the formation of new blood vessels and new supplies of peptide growth factors to the remaining tumour cells. It is at this time, when the tumour burden is at a minimum, that the treatment made possible by the present invention is most likely to be effective.

It is, indeed, a particular advantage of the present invention in accordance with one embodiment that it readily permits the simultaneous implantation of several different types of producer cells to target different phenotypic characteristics and microenvironmental factors influencing the progressive growth of brain or other tumours. For this purpose, a producer cell bank containing encapsulated producer cells stored frozen at the temperature of liquid nitrogen could be established. Producer cells could then be withdrawn from the bank to meet the genotypic expression of the host tumour being treated.

In order to establish what producer cells are required for treatment of a tumour the following procedure could be used, by way of example. Tumour characterization involving determination of receptor status and phenotype is first performed on biopsy material. Appropriately chosen producer cells which produce substances, for example monoclonal antibodies, directed against the receptor status of the host tumour is then implanted stereotactically up to 60 days following surgical removal of the primary tumour.

Alternatively, producer cells producing anti-angiogenic substances can be implanted directly following surgical removal of the primary tumour.

The dosage of producer cells to be implanted will, of course, depend on precise circumstances of each patient, but typically the total number of implanted cells would be in the range from 10^6 to 10^{12} per patient. The number of producer cells within each alginate or other encapsulating matrix will, of course, depend on the dimensions of the bead or other encapsulating form. The encapsulated producer cells will generally be surgically placed at the wound site following removal of the primary tumour.

As the experiments to be described in detail below have shown, encapsulated producer cells can survive, proliferate and maintain their specific expression periods *in vitro* and *in vivo*. This discovery opens up the possibility of a new kind of therapeutic treatment for patients with brain tumour conditions whereby different producer cells may be encapsulated which are chosen so as to target selected characteristics of brain tumour growth and development. In the experiments described herein, we have shown that specific MAbs released from alginate beads can inhibit tumour cell migration as demonstrated by an interference with epidermal growth factor receptor. We have also shown that specific products released from encapsulated producer cells within the brain penetrate into the brain parenchyma and can be distributed along CSF pathways.

The following experiments will assist in understanding the invention and its advantages. Hereafter reference will be made to the accompanying drawings, in which:

Figures 1A-1C

Light microscopic images of NIH 3T3 cells encapsulated in alginate. All bars represent 250 μm.

Fig. 1A: The day of encapsulation.

Fig. 1B: Encapsulated cells after 3 weeks in culture.

Fig. 1C: Encapsulated cells after 9 weeks in culture.

Figs. 1D-1F: Scanning confocal laser micrographs of NIH 3T3 cells encapsulated in alginate. Viable cells emit green fluorescence (here shown as lighter areas), while dead cells emit red fluorescence (not here visible). All bars represent 250 μm.

Fig. 1D: At the day of encapsulation.

Fig. 1E: Encapsulated cells after 3 weeks in culture.

Fig. 1F: Encapsulated cells after 9 weeks in culture.

Fig. 1G: β-Galactosidase activity of BT4CnV*lacZ* cells encapsulated in alginate, after 9 weeks in culture. Bar represents 500 μm.

Figures 2A-2D

Flow cytometric histograms of NIH 3T3 cells encapsulated in alginate beads. The horizontal axis expresses the number of channels on the flow cytometer (relative DNA fluorescence), while the vertical axis expresses the relative number of cell nuclei in each channel.

Fig. 2A: Control, monolayer culture.

Fig. 2B: Cells encapsulated for 1 week.

Fig. 2C: Cells encapsulated for 3 weeks.

Fig. 2D Cells encapsulated for 9 weeks.

Figure 3

Antibody release from H528 hybridoma cells encapsulated in alginate (mean value ± standard error). The horizontal axis represents the number of days in culture, while the vertical axis shows the antibody release into the growth medium. The curve was estimated by a 3rd order regression analysis.

Figure 4

Migration of cells from GaMg spheroids after 4 days, untreated (control), stimulated with 10 ng/ml EGF (EGF), or stimulated with 10 ng/ml EGF in the presence of encapsulated hybridoma cells (EGF/H528).

Figures 5A-5H

Encapsulated H528 hybridoma cells implanted into the rat brain.

Fig. 5A: Axial section of the rat brain. H&E-staining, bar represents 5 mm.

Fig. 5B: Same section as Fig. 5A, showing encapsulated H528 cells inside the implantation site. H&E-staining, bar represents 500 μm.

Figs. 5C-5H: Confocal laser scanning micrographs of the release and dissemination of monoclonal antibodies within the brain. Figs. 5C, E and F were taken with identical gain settings. Figs. 5G and 5H were also taken with identical gain settings.

Fig. 5C: A section of the brain parenchyma, with the encapsulated H528 cells at the far left side. Bar represents 150 μm. An intense fluorescence in the brain parenchyma is seen at the left side, followed by a gradual decrease in intensity at least 1000 μm into the brain.

The gradual change in fluorescence intensity along the horizontal line is further shown in Fig. 5D where the vertical axis represents the relative fluorescence intensity (0-255). An intense fluorescence is seen from the left side, with a gradual decrease into the brain parenchyma.

Fig. 5E: The MAbs were found in the subarachnoidal space and in the underlying brain. Bar represents 75 μm.

Fig. 5F: The weak fluorescence presented in the controls was probably caused by unspecific binding. Bar represents 75 μm.

Fig. 5G: MAbs were further spread within the perivascular space. Bar represents 50 μm.

Fig. 5H: In comparison, the controls showed a weak binding of immunoglobulins in the perivascular space. Bar represents 50 μm.

EXPERIMENTS

MATERIALS AND METHODS

1. Cell lines

In our experiments, four different cell lines were used:

	Cell Line	Deposit Details
1.	NIH 3T3	ATCC CRL/1658
2.	BT4CnV*lacZ*	Not deposited
3.	H528ATCC HB 8509	
4.	GaMgNot deposited	

The mouse fibroblast NIH 3T3 cells represents a potential producer cell line in that it is capable of being genetically engineered to express substances which show effects against tumour growth, progression and development. The NIH 3T3 cells were encapsulated in alginate, as described below and used to study *in vitro* morphology, viability and cell kinetics. For studies of the viability of encapsulated cells *in vivo*, alginate beads containing NIH 3T3 cells were also implanted into the rat brain.

The BT4CnV*lacZ* cell line was originally developed from an ethylnitrosourea induced rat glioma and stably transfected with the bacterial *lacZ* gene, cloned into a plasmid containing a Moloney murine leukaemia virus long terminal repeat cassette with a neomycin resistance gene expressed from an internal Rous sarcoma virus promoter. See J. Natl Cancer Inst, 55 (1975), pages 1177-87 and Int. J. Cancer, 71 (1997), pages 874-80. The cells were encapsulated in alginate, and the *in vitro* synthesis of the bacterial β-galactosidase was studied.

The H528 hybridoma cell line was obtained from American Type Culture Collection (ATCC Rockville, MA). The cell line was generated by fusing NS-1-Ag4-1 myeloma cells with spleen cells from BALB/c mice, and it produces a mouse monoclonal antibody (MAb) (IgG2a) that binds to and blocks the EGF-binding domain of the human epidermal growth factor receptor (EGFR). The *in vitro* and *in vivo* MAbs release from the alginate encapsulated cells was studied using this cell line.

The human glioma cell line GaMg has been described in Anticancer Res, 8 (1988) pages 874-80, and has previously been shown to express the EGFR (Acta Neuropathol Berl, 84 (1992), pages 190-197. The specific inhibition of GaMg cell migration was studied in a co-culture system between GaMg multicellular spheroids and encapsulated H528 cells.

2. **Cell culture**

The NIH 3T3 and the BT4CnV*lac*Z cell lines were grown in 80 cm^2 culture flasks (Nunc, Roskilde, Denmark) with complete growth medium consisting of Dulbecco's modified Eagles medium (DMEM) supplemented with 10% heat inactivated newborn calf serum, four times the prescribed concentration of non-essential amino acids, 2% L-Glutamine, penicillin (100 IU/ml) and streptomycin (100 µg/ml) (all biochemicals from BioWhittaker, Verviers, Belgium). The H528 hybridoma and the GaMg cell lines were grown in 80 cm^2 culture flasks (Nunc) in RPMI 1640 growth medium supplemented with 10% horse serum (BioWhittaker). GaMg monolayers were trypsinized at confluence with 3 ml of 0.025% trypsin (BioWhittaker), and spheroids were initiated by seeding $5*10^6$ cells in 20 ml of complete RPMI medium into 80 cm^2 culture flasks (Nunc) base-coated with 0.5% agar noble (Difco, Detroit,

MI)(30) in complete RPMI medium. All cell lines were kept in a standard tissue culture incubator at 37°C, with 100% relative humidity, 95% air and 5% CO_2.

3. Structure and properties of alginate

In these experiments sodium alginate from the brown seaweed Laminaria hyperborea (LF 10/60) (Protanal, Drammen, Norway) was used for microencapsulation of the producer cells. This consists of two monosaccharides; α-L-guluronic acid (G) and β-D-mannuronic acid (M). The G- and M-units are joined together in three different types of blocks, GG, MM and MG, and the proportions and distributions of these blocks determine the chemical and physical properties of the alginate molecules. Some divalent cations like CA^{2+} bind strongly between separate G-blocks, which initiate the formation of an extended alginate network where the G-blocks form stiff junctions. The alginate which we used has a high content, above 60%, of G-blocks, resulting in high mechanical stability and porosity, rendering it suitable for encapsulating cells for production of secondary metabolites (see Trends in Biotechnology, 8 (1990), pages 71-78). Scanning electron microscopy has showed pore sizes in the alginate beads to range between 5 and 200 nm (33,34). Mechanical strength, volume stability and porosity of the beads correlate to the content of guluronic acid.

4. Encapsulation of cells

The method of encapsulation used has been described in detail in "Alginate as Immobilization Matrix for Cells" by Smidsrød and Skjak-Braek in Trends in Biotechnology, March 1990, Vol. 8, No. 3, pages 71-78.

Briefly, droplets of cells dispersed in 1.5% sodium alginate were released into a 0.1M Ca^{2+}-solution. After polymerization, the alginate beads were washed three times in Dulbecco's PBS (DPBS; Sigma, St. Louis, MO), and once in growth medium. The encapsulated cells were cultured in 175 cm^2 culture bottles (Nunc), containing 50 ml growth medium. The growth medium was changed every third day, and the bottles were replaced once a week. All alginate encapsulated cells were kept in a standard tissue culture incubator at 37°C, with 100% humidity, 95% air and 5% CO_2. For all the experiments with the NIH 3T3 and the BT4CnV*lac*Z cell lines, a cell density of $6*10^6$ cells/ml alginate and bead sizes between 0.8 and 1.2 mm were used. For the *in vitro* experiments with the H528 cell line a cell density of $3*10^5$ cells/ml alginate and bead diameters between 2.3 and 2.5 mm were used. For the *in vivo* experiments with the H528 cell line, a cell density of $3*10^5$ cells/ml alginate and bead diameters between 0.8 and 1.2 mm were used.

IN VITRO **EXPERIMENTS**

1. Morphology and viability of alginate encapsulated cells

The morphology of NIH 3T3 cells encapsulated in alginate was investigated at the day of encapsulation, and after 3 and 9 weeks, in 6 beads transferred to a 6-well dish (Nunc) with an overlay of 1.0 ml DPBS. The beads were examined with a Nikon Diaphot light microscope, and photographed with a Nikon F-301 camera. The morphology experiments were performed in duplicate.

The viability of the cells within the alginate beads was investigated at the day of encapsulation, and after 3 and 9 weeks, by a two-colour fluorescence viability assay (Live/Dead™ Viability/Cytotoxity Assay,

Molecular Probes, Eugene, OR). A labelling solution was prepared with 2 μM calcein-AM and 4 μM ethidium homodimer in complete growth medium. The alginate beads were individually placed in 16-mm multiwell dishes (Nunc) with an overlay of 0.5 ml labelling solution of 30 minutes at room temperature. Thereafter they were transferred into DPBS and examined immediately. The fluorescence was measured in optical sections through the alginate using a confocal laser scanning microscope with an argon-krypton laser (Biorad MRC-1000, Hemel Hempstead, England), using Texas Red and FITC filter optics. Fluorescence was recorded in a plane 120 μm inside the alginate beads. The viability experiments were performed in triplicate.

The production of β-galactosidase in BT4CnV*lacZ* cells encapsulated in alginate for 1, 3 and 9 weeks was studied. The beads were washed for 1 minute in DPBS (pH = 8.4), and fixed for 10 minutes in 0.2% glutaraldehyde and 2% formaldehyde in DPBS. Thereafter they were washed 3 x 5 minutes in DPBS and stained for β-galactosidase activity with 5-bromo-4-chloro-3-indolyl β-D-galacto-pyranoside (x-gal; Sigma). The substrate solution consisted of 1 mg/ml x-gal dissolved in 100 μl dimethylformamide, and mixed with 5 mM potassiumferri-cyanite, 5 mM potassiumferrocyanate and 2 mM $MgCl_2$ dissolved in DPBS (all biochemicals from E. Merck, Darmstadt, Germany). They were incubated at 4°C for minimum 24 hours, and examined for β-galactosidase activity, represented by a blue coloured cell cytoplasm.

2. Cell kinetics of alginate encapsulated cells

The *in vitro* cell cycle distribution of the encapsulated NIH 3T3 cells was determined by flow cytometric DNA analysis. The encapsulated cells were released from the alginate by dissolving the beads in

complete growth medium containing 1.5% tri-sodium citrate dihydrate (E. Merck) for 15 minutes, followed by centrifugation at 140 g for 4 minutes, and removal of the supernatant. The cells were re-suspended twice in complete growth medium, centrifuged at 140 g for 4 minutes, fixed in ice cold 96% ethanol and stored at 4°C. Prior to the flow cytometric analysis, the cells were incubated for 15 minutes with 0.5% pepsin (Sigma) in 0.9% physiological saline (pH = 1.5) at 37°C before the isolated nuclei were washed in 0.9% physiological saline, and treated for 1 minute with ribonuclease (Sigma) (1 mg/ml in 0.9% physiological saline). Staining of DNA was obtained by adding propidium-iodide (Sigma) (50 μg/ml in 0.9% physiological saline) to the nuclei. The cellular DNA content was measured using a Becton Dickinson FACSort flow cytometer (Becton Dickinson, Palo Alto, CA). The DNA histograms were obtained by gating a two parameter forward- and side-scatter cytogram to a one parameter DNA histogram. Each histogram was obtained by counting a total of 5000 gated nuclei. The flow-cytometric experiments were repeated three times, and the cell cycle distribution was determined as described in Radiat Environ Biophys, 12 (1975), pages 31-39.

3. **Antibody release from the encapsulated hybridoma cells**

Alginate beads with diameters between 2.3 and 2.5 mm containing $1.5*10^3$ H528 cells per bead on the day of encapsulation were prepared as described above. After 0, 1, 5, 12, 19, 23, 30 and 33 days, respectively, 10 beads were removed from the stock culture and the release of Mabs into the RPMI medium was examined. The beads were transferred into 24 well dishes (Nunc), in 0.5 ml complete RPMI medium (37°C). After 6 hours of incubation, four samples of 100 μl each were collected, placed in 1.5 ml centrifuge test tubes (Treff AG, Degersheim, Switzerland) and frozen at -20°C).

Flow cytometry was used to determine the concentration of MAbs in the samples. GaMg monolayer cell cultures were typsinized with 2 mM EDTA in DPBS. The cells were then centrifuged at 140 g for 4 minutes, the supernatant was removed, and the cells were fixed in 2% paraformaldehyde solution in DPBS for 1 minute. Thereafter the cells were centrifuged at 140 g for 4 minutes, and the supernatant was removed. The cells were then re-suspended in DPBS containing 2 mM EDTA, 1% bovine serum albumine and 1 g/l glucose, and distributed in a conical 96 well plate (Nunc) with $1.7*10^5$ cells/well. The cells were centrifuged at 340 g for 4 minutes, and the supernatant was removed. Thereafter the cells were vortexed and incubated for 2 hours at 4°C with the harvested MAb RPMI medium (undiluted, and 1:5, 1:20 and 1:100 dilutions in DPBS). As a reference, an EGFR MAb (528) antibody (Santa Cruz Biotechnology, Santa Cruz, CA) with a known MAb concentration was used (concentrations 20, 5, 1, 0.2, 0.1 and 0.05 μg/ml). The cells were washed twice in 2 mM EDTA, 1% BSA, 1 g/l glucose in DPBS, and then incubated with FITC-conjugated goat anti-mouse immunoglobulins (Dako A/S, Glostrup, Denmark) (1:20 dilution) for 30 minutes at 4°C. Flow cytometry was performed on a Becton Dickinson FACSort flow cytometer. Single cells were detected and visualized by a two parameter forward- and side-scatter cytogram and gated to a one parameter FITC histogram, where the fluorescence intensity was determined. By using the various titers of the EGFR MAb with a known concentration on the GaMg cells, a reference antibody binding curve to GaMg cells was obtained. By comparing the results obtained from medium harvested from the hybridoma containing alginate beads, the MAb concentration curve was obtained.

4. **Cell migration**

GaMg spheroids were individually transferred to 16-mm multiwell dishes (Nunc), in 1.0 ml complete RPMI medium containing 10 ng/ml EGF (Sigma). Thereafter, the tumour cells were exposed to alginate beads containing H528 cells (three alginate beads in each well). As controls, spheroids were exposed to complete RPMI medium with or without 10 ng/ml EGF. The orthogonal diameter of each colony was measured daily for four days, using a light microscope with a calibrated reticle in the ocular. The circular area covered by the cells migrating out from the spheroids was then determined and used as an index of cell migration. The experiments were performed in duplicate, with six spheroids in each experiment.

IN VIVO **EXPERIMENTS**

1. **Intracranial implantations**

Male inbred BD-IX rats (36) weighing between 160 g and 250 g were kept on a standard pellet diet, given unlimited access to tap water and caged individually at a constant temperature and humidity on a 12 hour light and dark schedule. The rats were anaesthetized intraperitoneally with pentobarbitol at a concentration of 0.4 ml/100 g body weight. Via a mid-sagittal skin incision, a burrhole was made with a 3.5 mm drill 4.2 mm posterior to the bregma point and 2.5 mm to the right of the sagittal suture. Cortical and white matter tissue was removed by suction to a depth of 2.0 mm, and between 8 and 14 alginate beads (one day old beads) containing either NIH 3T3 cells or H528 cells were placed in the tissue cavity. The burrhole was closed with bone wax and the skin sutured with polyamide thread. Recovery under a heating lamp was allowed for 1 hour.

The animal care was in accordance with institutional guidelines. The rats were observed once a day, and weighed every other day. All animals recovered quickly after the implantations, and did not show any signs of illnesses or neurological deficits during the observation period.

2. Release and dissemination of immunoglobulins within the rat brain

After 3 and 9 weeks, the rats were sacrificed by CO_2 inhalation. The brains were removed, embedded in Tissue Tek (Miles Laboratories Inc., Naperville, IL) and frozen in 2-Methylbutane (E. Merck) cooled with liquid nitrogen. Axial sections (14 μm) were cut on a Reichert-Jung cryocut 1800 cryotome (Leica, Wetzlar, Germany), and stored at -20°C. Cryosections obtained from rats implanted with H528 encapsulated cells and sacrificed after 3 weeks, were fixed in acetone for 5 minutes at room temperature, and then washed twice in DPBS for 5 minutes. The sections were then incubated with FITC-conjugated goat anti-mouse immunoglobulins (Dako A/S; 1:20 dilution) for 1 hour at room temperature, and thereafter washed for 5 minutes with DPBS. The sections were treated for 30 seconds with ribonuclease (Sigma) (0.5 mg/ml in 0.9% physiological saline), and staining of the nuclei was obtained by adding propidium-iodide (Sigma) (50 μg/ml in 0.9% physiological saline) to the sections. Furthermore, the sections were washed with DPBS for 5 minutes, and then mounted with Vectashield (Vector Laboratories Inc, Burlingame, CA).
The fluorescence was measured using a Leica TCS NT confocal laser scanning microscope with an argon-krypton laser (Leica), using TRITC and FITC filter optics. Sections taken from the same depth within the brains of the experimental animals were investigated, and the areas

of maximum fluorescence intensity were studied in both groups. Cryosections obtained from rats implanted with NIH 3T3 cells and sacrificed after 9 weeks, were stained with Haematoxylin and Eosin for histological examination.

RESULTS

IN VITRO EXPERIMENTS

1. Morphology and viability of the alginate encapsulated cells

Alginate beads with diameters of 1.0 mm contained approximately $6.5*10^2$ NIH 3T3 cells on the day of encapsulation (Fig. 1A). The cells were evenly distributed within the alginate beads, with an outer cell free rim of 25-50 μm. During culture, cell proliferation was observed within the alginate, resulting in an increased cellular density after 3 weeks (Fig. 1B). After 9 weeks in culture, multicellular spheroids were observed within the alginate beads (Fig. 1C). Over 90% of the beads remained intact after 9 weeks in culture, as assessed by light microscopy. After about a week in culture a few single cells migrated out from the alginate beads and into the growth medium, and this limited movement of single cells continued during the next 8 weeks of culture.

The confocal laser scanning microscopy study showed that around 90% of the encapsulated cells remained viable on the day of encapsulation (Fig. 1D). After 3 weeks in culture, around 50% of the originally encapsulated cells were viable (Fig. 1E). Some of the surviving cells adapted to the alginate and formed viable multicellular spheroids, which could be clearly observed after 9 weeks (Fig. 1F). At this time point the total

number of viable cells within the beads were difficult to assess due to the multicellular spheroid formation. However, as shown in Fig. 1F, most of the cells localized in the spheroids were viable.

The encapsulated BT4CnV*lac*Z cells expressed a constant and evenly distributed β-galactosidase activity during the whole observation period of 9 weeks (Fig. 1G).

2. **Cell kinetics of alginate encapsulated cells**

The flow cytometric histograms of the NIH 3T3 cells showed a change in cellular ploidy within the alginate beads 1 week after encapsulation (Fig. 2B). This probably represents a polyploidization, as compared to the diploid control (Fig. 2A). However, after 3 and 9 weeks respectively (Fig. 2C, 2D) a normalization in ploidy was observed, with a similar diploid distribution as for the controls. The fraction of proliferating cells in the S and G_2M phases was 50% for the control, as compared to 55% and 60% after 3 and 9 weeks *in vitro*, respectively.

3. **Antibody release from the encapsulated hybridoma cells**

Already at the end of the first day of encapsulation, there was a release of 13 ng/(ml*hr) of MAbs in the growth medium (Fig. 3). The diffusion of immunoglobulins out of the beads and into the medium increased steadily during the next days of culture, and reached a concentration of 457 ng/(ml*hr) after 12 days. The production of MAbs then stabilized around 400 ng/(ml*hr) during the last 3 weeks of the observation period.

4. **C ll migration**

The migration of cells out from the GaMg spheroids stimulated with EGF was extensive, and the mean outgrowth area was doubled, compared to the controls (Fig. 4). However, when alginate beads containing H528 cells were added in the presence of EGF, cell migration was strongly inhibited, demonstrating that the encapsulated H528 producer cells effectively express an antibody directed against the EGF receptor.

IN VIVO **EXPERIMENTS**

1. **Intracranial implantations**

Axial sections of the rat brains revealed little or no change in the brain parenchyma adjacent to the implantation site harbouring the alginate encapsulated NIH 3T3 cells (Fig. 5A). Little intracranial edema or swelling was observed after 9 weeks. The alginate beads were free of any cell overgrowth, and contained both viable single cells and multicellular spheroids (Fig. 5B). The viable cells were distributed both in the centre and in the periphery of the beads, with cell-free areas of alginate in between the cells. A minimal aggregation of cells around the border zone between the implantation hole and the brain parenchyma was observed.

2. **Release and dissemination of immunoglobulins within the rat brain**

The implanted beads with encapsulated hybridoma cells were easily visualized after 3 weeks by an intense green fluorescence (Fig. 5C). Immunoglobulins were detectable in the brain tissue at a distance of at least

1 mm from the alginate beads (Figs. 5C, 5D), with a gradual decrease in fluorescence intensity from the border of the implantation site and into the brain. For two of the experimental animals, MAbs were detected in the whole cerebral hemisphere, where the implants were located (data not shown). MAbs were further found in the leptomeninges in both hemispheres of the cerebrum (Fig. 5E), with the strongest fluorescence seen in the subarachnoidal area in the right hemisphere. The negative controls showed a weak fluorescence in the leptomeninges, probably caused by non-specific binding between the immunoglobulins and epitopes on the leptomeningeal cells (Fig. 5F). However, the brain parenchyma was negative. The MAbs were further present in the perivascular space of intracerebral blood vessels, with no apparent difference in fluorescence intensity between the two hemispheres (Fig. 5G). The weak fluorescence present in the control was again probably caused by non-specific binding (Fig. 5H).

DISCUSSION

The results of the above-described experiments clearly demonstrate that the microencapsulated cells survive, proliferate and maintain their phenotypic expression over extended time periods. It is also shown that MAbs released from the alginate beads have the ability to inhibit tumour cell migration *in vitro* by interfering with the EGFR, and that MAbs are released and disseminated within the rat brain.

As seen by light microscopy, the NIH 3T3 cells adapted to the alginate *in vitro*, and started to proliferate within a few days after encapsulation. The CLSM study revealed cell viability around 90% at the day of encapsulation. During the first three weeks in

culture, around 50% of the initially entrapped cells died within the beads. However, after 9 weeks, the remaining cells showed the ability to form multicellular spheroids within the alginate. An observed cell death within the alginate has also been reported by others, and may be due to a reduced diffusion of oxygen, nutrients and waste products, which may eventually lead to an equilibrium between the number of proliferating and dying cells. A more favourable diffusion rate may be achieved by decreasing bead size, increasing the content of G-units, which would increase the pore sizes, or changing the alginate concentration. In addition, the diffusion is dependent on the number of initially encapsulated cells within the beads. The alginate itself is non-toxic, and can therefore not be expected to contribute to the observed cell death within the beads.

The BT4CnV*lacZ* cells exhibited a strong and evenly distributed β-galactosidase activity during 9 weeks of culture. These results demonstrate that also specific gene products may be produced during prolonged periods within alginate beads.

The flow cytometric study showed that the NIH 3T3 cells changed from a diploid to a multiploid population after 1 week in alginate. This indicates that the cell nuclei divide, but because of limited space within the rigid alginate network, the cells are initially not able to undergo cytokinesis. This will then result in single cells with double and triple nuclei (Fig. 2B). However after 3 weeks, the cell cycle distribution was similar to the controls. This may indicate that the cells need a certain adaptation period within the alginate, were single cells with double and triple nuclei will either finish their cytokinesis or die. The histograms after 9 weeks were similar to those

after 3 weeks, but indicated an increase of cells in the proliferating phases. The analysis of the cell cycle distribution showed an increase in the number of proliferating cells, from 50% for the control, to about 60% after 9 weeks. This may be due to a selection within the alginate beads of cells with a higher proliferative capacity during prolonged culture of the NIH 3T3 cells.

The antibody release from the encapsulated H528 hybridoma cells was substantially constant at around 400 ng/ml*hr from day 12 to day 33, which shows that a stable density of MAb-secreting hybridoma cells had been established after 12 days in culture. This finding is important for the clinical situation, as it shows stable monoclonal antibody production is achieved at a high level.

The cell migration out from the GaMg spheroids was stimulated in the presence of EGF. By adding H528 encapsulated cells to the EGF stimulated spheroids, the migration was inhibited, and the outgrowth area was similar to the controls. This implies that paracrine cell proliferation mechanisms are inhibited by these Mabs, probably by blocking the EGF-binding domain of the EGFR.

Implantation of alginate-encapsulated producer cells in other organs outside the central nervous system (CNS) has shown a fibroblast overgrowth of the alginate beads, leading to cell death and graft failure (Transplantation, 54 (1992), pages 769-774). Due to the unique location, and the lack of fibroblasts in the CNS, the same cell overgrowth was not observed in the present study (Fig. 5A, B). Depending on the composition, alginates have in some instances been shown to trigger an immune response within the body by stimulating monocytes

to produce high levels of cytokines. The cytokine-stimulating part of the alginate are the M-units. An alginate with a high content of G-units was therefore chosen for our experiments, in order to minimize the immune response within the brain. In further experiments we have found a low immune response towards alginate encapsulated cells within the brain, with only some microglial cells assembling in the brain tissue close to the implanted beads. These observations further show alginate-encapsulated producer cells to be an attractive treatment within the brain. A minimal aggregation of cells around the border zone between the implantation site and the brain parenchyma was also seen. This may be due to NIH 3T3 cells escaping from the alginate beads, because of a mild immune response towards the implants as discussed above, and/or due to a tissue wound-healing process. It is, however, not considered that the small number of producer cells which escape the alginate represents a problem, since these cells would be taken care of by normal graft versus host rejection mechanisms.

However, if desired, steps can be taken to prevent cell escape eg by covering the beads with a layer of poly-L-lysine or by irradiating the cells prior to encapsulation, thereby inhibiting their proliferative capacity. The immunoglobulins were released from the alginate beads, and disseminated into the brain parenchyma at a distance of at least 1 mm away from the border of the implantation site. In two of the experimental animals, MAbs were also detected in the whole cerebral hemisphere where the implants were located. This dissemination may be due to a passive diffusion process. MAbs were also localized in the subarachnoidal area and within the perivascular space of Virchov-Robin. This spread is most likely mediated by the constant flow of cerebrospinal fluid within the CNS.

Interestingly, tumour cells follow the same dissemination

pathways within the brain, which make them accessible to components produced by alginate encapsulated cells.

In summary, the experiments which are described above show that encapsulated producer cells survive and proliferate within the alginate for prolonged time periods, *in vitro* as well as *in vivo*. Gene products such as β-galactosidase are produced within the cell cytoplasm of the encapsulated BT4CnV*lac*Z cells during several weeks of culture. Encapsulated hybridoma cells further produce and release high amounts of MAbs *in vitro* and *in vivo*. The GaMg tumour cell migration is inhibited in the presence of encapsulated H528 cells. Implants of encapsulated H528 cells also produce and release MAbs within the rat brain, and the MAbs disseminate within the brain parenchyma, as well as within the subarachnoidal and in the perivascular space. The present invention therefore represents a promising tool for CNS tumour therapy.

CLAIMS:

1. An encapsulated producer cell capable of expressing a molecule which is an inhibitor of CNS tumour growth.

2. An encapsulated producer cell according to Claim 1, wherein said molecule is a protein or peptide capable of interacting with tumour/host communication pathways.

3. An encapsulated producer cell according to Claim 2, wherein said protein or peptide is capable of affecting tumour neovascularization.

4. An encapsulated producer cell according to Claim 2, wherein said protein or peptide is capable of interfering with the relationship of the tumour cell with the extracellular matrix.

5. An encapsulated producer cell according to Claim 1, wherein said molecule is a protein or peptide capable of interacting directly with the tumour cell.

6. An encapsulated producer cell according to Claim 5, wherein said producer cell is a hybridoma cell capable of expressing a monoclonal antibody capable of interacting directly with a receptor of the tumour.

7. An encapsulated producer cell according to any preceding claim, wherein said expression of said molecule is capable of being switched on and off by an external pharmacological agent.

8. An encapsulated producer cell according to any preceding claim, wherein the encapsulating matrix is a biocompatible polymer.

9. An encapsulated producer cell according to Claim 8, wherein said biocompatible polymer is an alginate.

10. An encapsulated producer cell according to Claim 9, wherein said biocompatible polymer is calcium alginate.

11. An encapsulated producer cell according to any one of Claims 8-10 in the form of beads.

12. An encapsulated producer cell according to any preceding claim, wherein said tumour is a brain tumour.

13. A method for the treatment of CNS tumour, which comprises implanting at the site of the tumour an encapsulated producer cell which is capable of expressing a molecule which is an inhibitor of the growth of said tumour.

14. A method according to Claim 13, wherein said encapsulated producer cell is as defined in any one of Claims 2-12.

15. A method according to Claim 13 or Claim 14, wherein said producer cells are implanted following surgical removal of said tumour.

16. A method for the preparation a pharmacological product for the treatment of a CNS tumour, which comprises encapsulating within an immuno-isolating matrix a producer cell capable of expressing a molecule which is an inhibitor of the growth of said tumour.

17. A method according to Claim 16, wherein said matrix comprises alginate beads.

ABSTRACT

Encapsulated producer cells which are capable of expressing a molecule which is an inhibitor of CNS tumour growth provide a novel approach to the treatment of tumours, such as brain tumours which are localized within the central nervous system.

Fig.1.

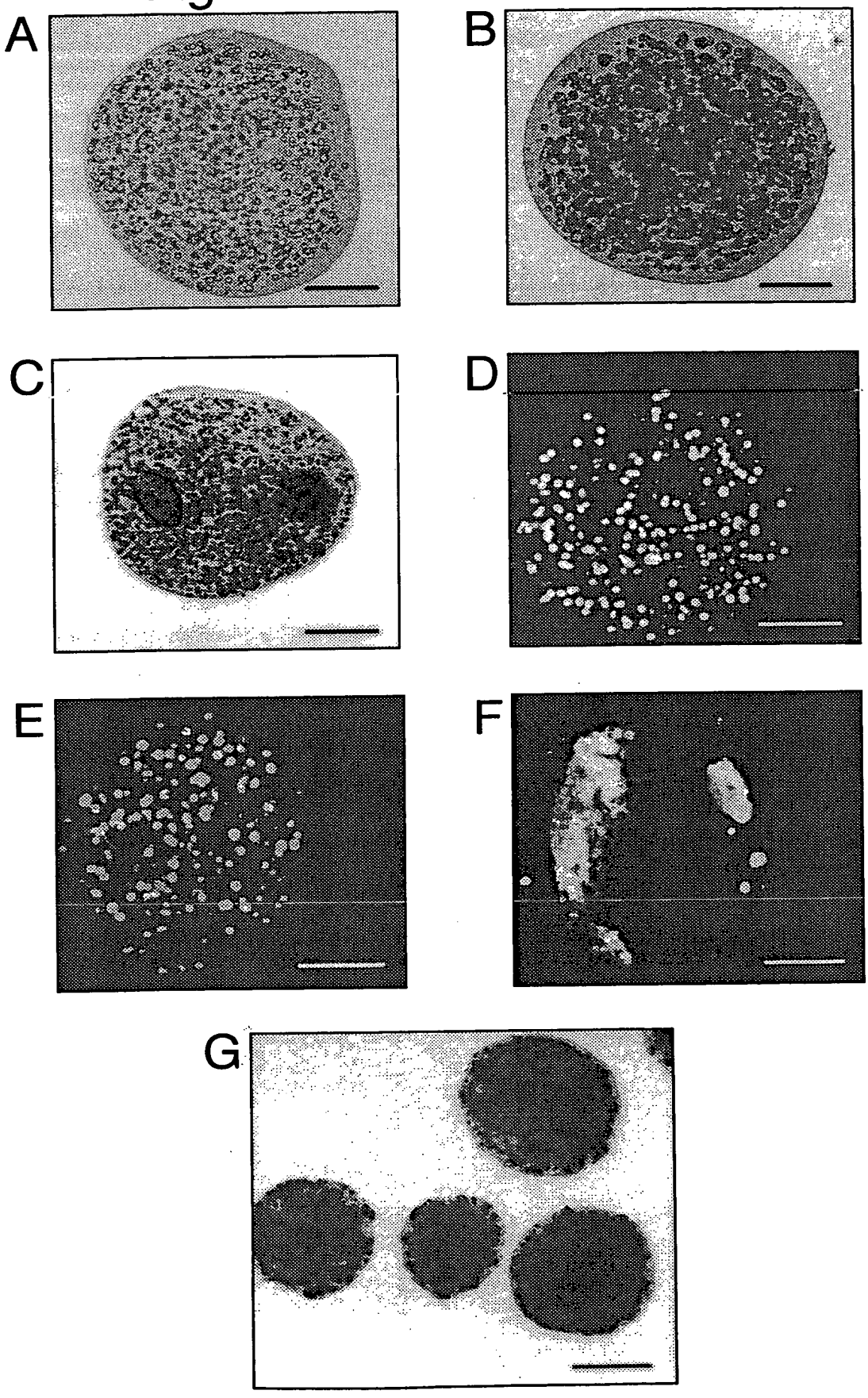

Fig.2.

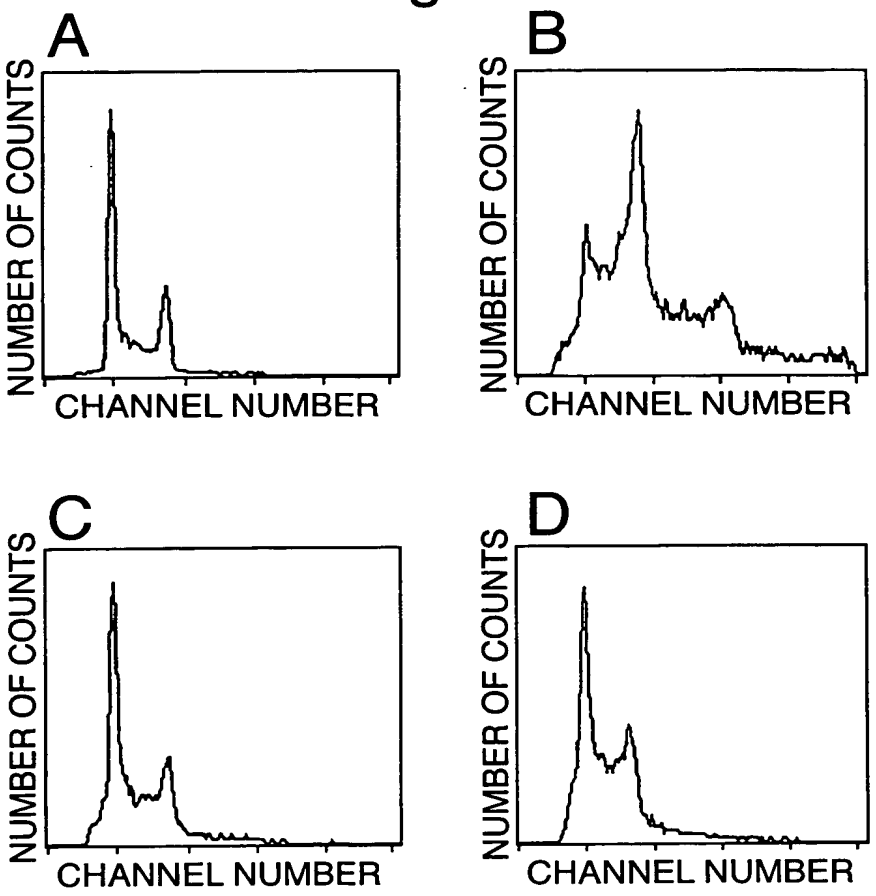
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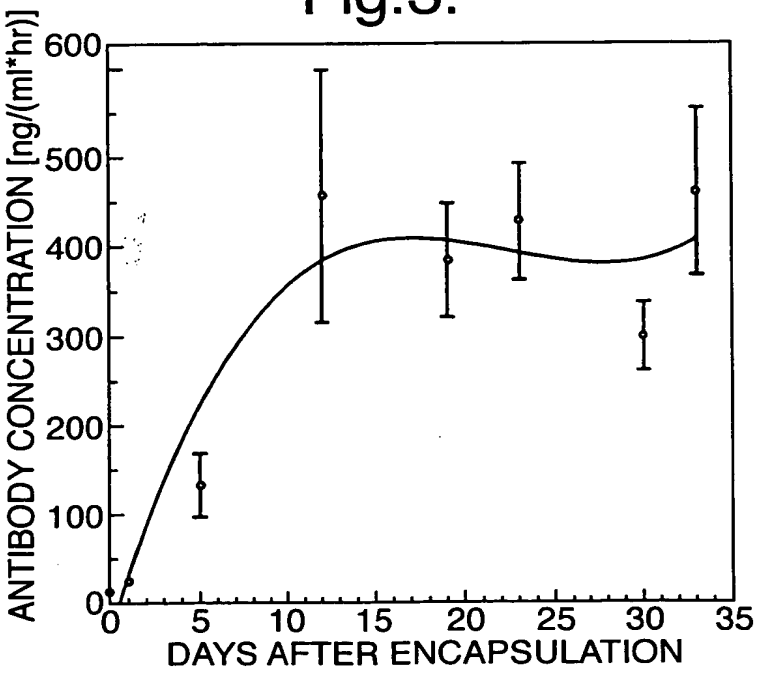
Fig.3.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35
DAYS AFTER ENCAPSULATION

Fig.4.

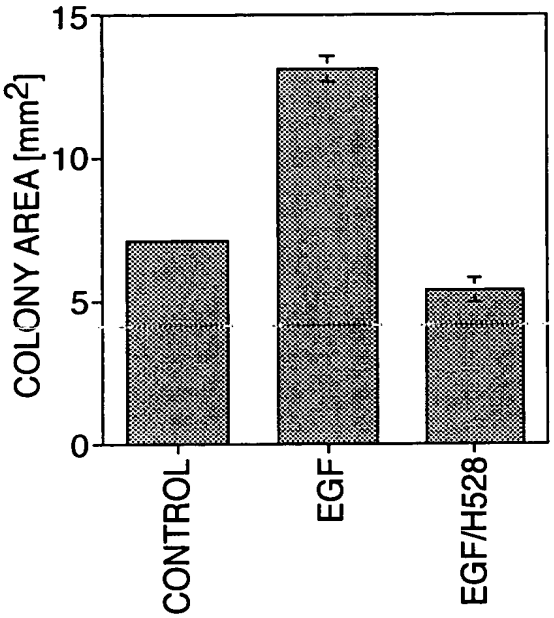


Fig.5.

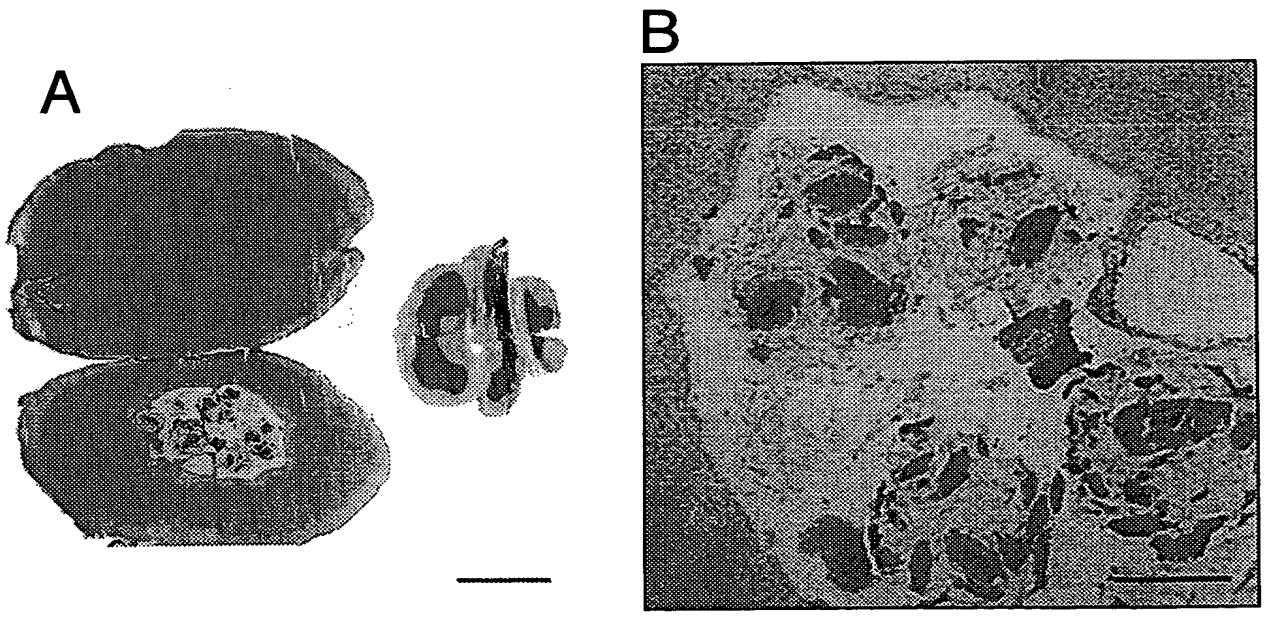
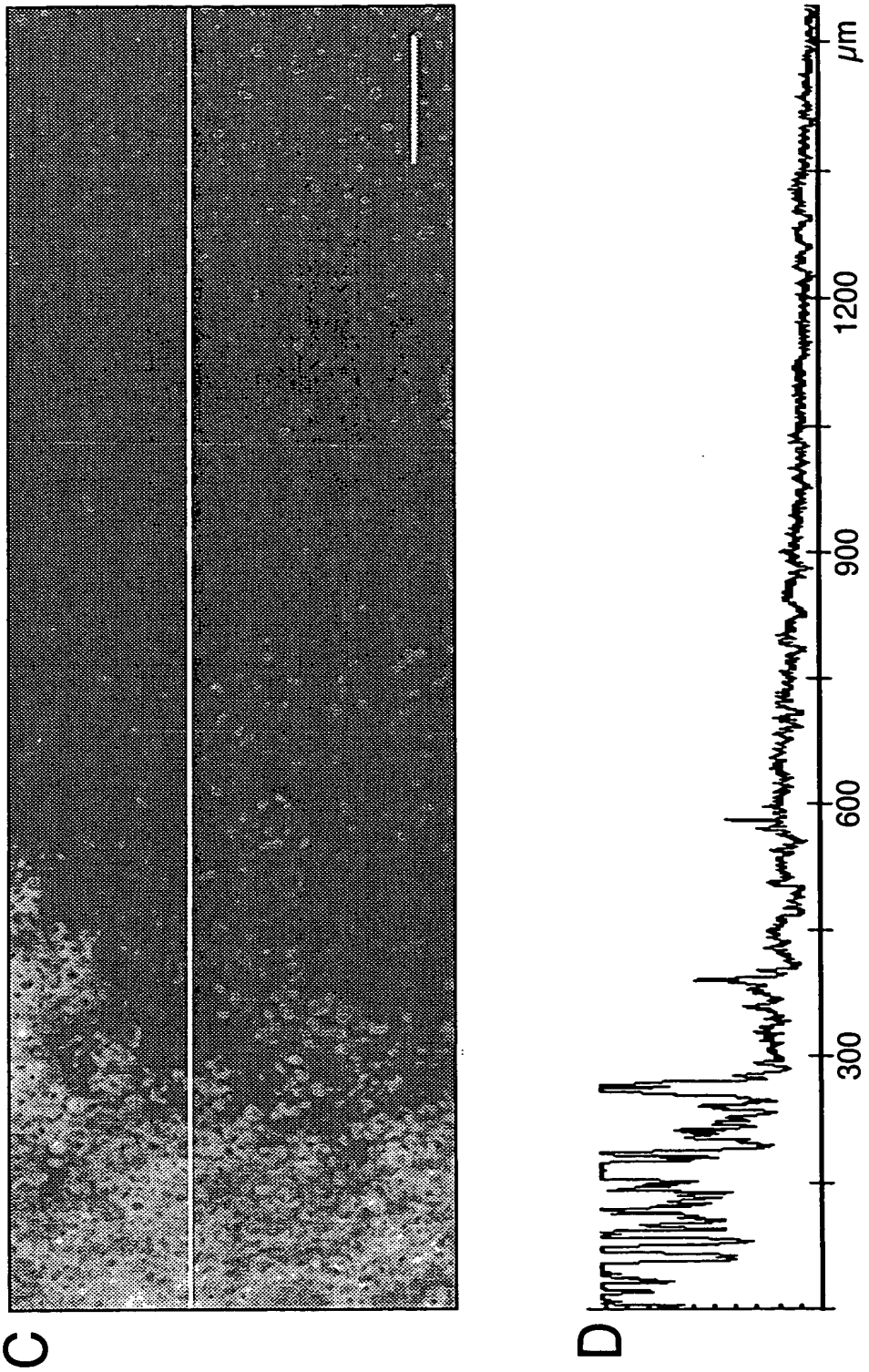


Fig.5 (Cont i).



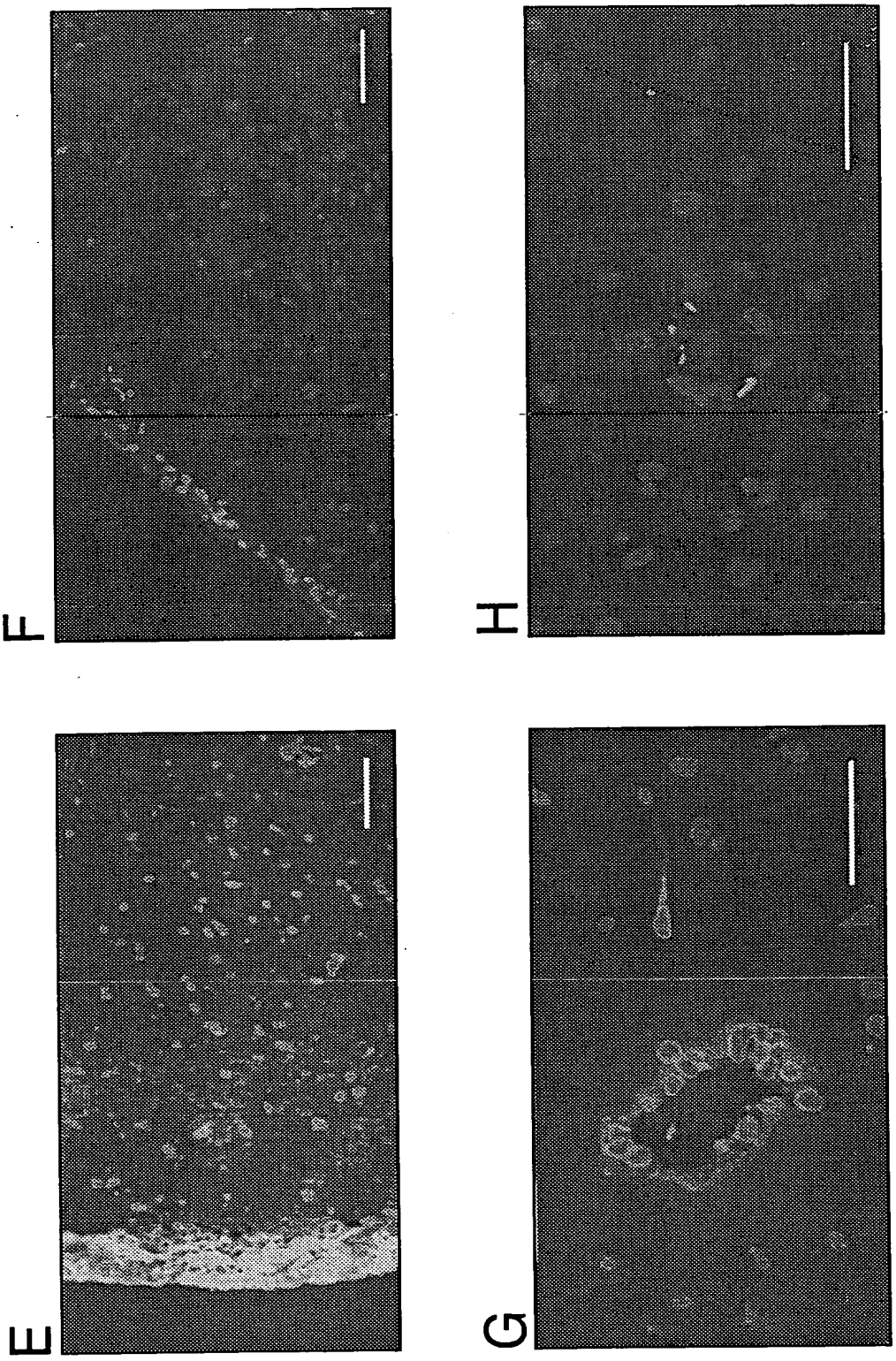


Fig.5 (Cont ii).

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